Eno
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Beyond Speculation

Automated Vehicles and Public Policy

An Action Plan for Federal, State, and Local Policymakers

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About Eno and the Digital Cities Project

The Eno Center for Transportation is an independent, nonpartisan think tank that promotes policy innovation and leads professional development in the transportation industry. As part of its mission, Eno seeks continuous improvement in transportation and its public and private leadership in order to improve the system's mobility, safety, and sustainability.

Eno's Digital Cities project is a multi-part research and outreach effort intended to provide a resource for policymakers to understand the technological forces that are shaping our transportation networks.

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Executive Summary

Automated vehicle (AV) technology has the potential to completely change how we travel, how we ship goods, and on a larger scale, how we think about mobility. While fully automated vehicles are not yet commercially available, the technology is developing rapidly and some robotic driving functions are already on public roads today.

The governments are under pressure to craft regulations and make investments that encourage innovation while still enhancing safety and protecting the public interest. In 2016, the National Highway Traffic Safety Administration (NHTSA) developed its Federal Automated Vehicles Policy, the first step in creating a federal AV policy. Meanwhile, thirty-nine states and the District of Columbia have proposed or enacted a variety of AV policies, resulting in a troublesome patchwork of laws and regulations that are often inconsistent.

As part of Eno's Digital Cities program, Eno crafted a multifaceted set of recommendations that address the most pressing policy issues for AVs. If applied and executed properly, these recommendations will help guide this technology towards safe, efficient, and sustainable deployment.

AVs are upending the traditional definitions of ***licensing***, ***liability***, and ***insurance*** for automobiles. In a future where computers are increasingly responsible for operating cars, determining blame in a car crash has become less clear. In response, Congress should pass legislation allowing NHTSA to create AV system certifications and should support the harmonization of state tort laws that explicitly align liability with the certifications and roles of the automated features and the human driver. For their part, states should create stakeholder working groups to oversee the development of state and local laws.

AVs and connected vehicles will be accompanied by a deluge of ***data*** and, consequently, the need for an increased focus on ***cybersecurity***. NHTSA should explicitly define that the ownership of the vehicle's data corresponds to the operator of the vehicle. Due to the sensitivity of the data being collected, Congress should explicitly require the AV industry to protect the privacy of vehicle owners. Congress should also define AV developers' limited liability for crashes that result from a security breach. States and cities should establish data sharing agreements to enhance local transportation planning and operations.

Existing ***infrastructure*** will also need to be maintained and updated to accommodate AVs. At the state and local level, investments need to be made in in robust "state of good repair" programs that will benefit all users of public roads, regardless of the degree of automation. This poses significant ***funding*** barriers for cities and states that may already be struggling to maintain their roads. To help, Congress should develop a per-mile charge fee system for AVs.

Increased ***vehicle connectivity*** can also maximize the safety and efficiency benefits of AVs. While AVs do not require integration, some experts have suggested that AVs must be connected in order for them to reach their full potential. The Federal Communications Commission (FCC) should continue to allocate a spectrum of dedicated short range communications channel to enable vehicle connectivity. NHTSA should also continue to work closely with the automotive industry on standards for connected vehicle communications.

Federal safety programs are vital for cities and states trying to improve roadway safety. Congress should make the implementation of AV technologies eligible for federal safety programs to improve transportation operations.

AV deployment could not only help make driving safer and more efficient but, if deployed under a shared fleet model, could also reduce the ***environmental impact*** of driving. Congress should create a federal transportation discretionary grant program that targets projects that meet both environmental and accessibility goals. In the long run, cities, counties, metropolitan planning organizations, and state departments of transportation should consider the potential impacts of AVs on regional transportation systems and include them in their long-range plans. Furthermore, states and cities should consider using pricing structures to mitigate negative externalities of AVs.

Because AVs are advancing at such a rapid rate, ***research investment*** is critical. While private sector companies have already devoted resources in the development of new technology, governments should fund AV research programs at local universities that explore the wider transportation effects of AVs on the roadway.

As the capabilities of AVs continue to develop and saturate the market for vehicles, there is a chance that workers in the maintenance, taxi, and delivery service industries will be gradually replaced. While it is hard to say exactly how automated driving will affect the nation's ***workforce***, the potential loss of millions of jobs is a threat to social and economic stability. To prepare, governments should work with academic institutions to retrain workers whose jobs are lost to automation.

Sound public policy is an essential component in preparing for the eventual deployment of AVs. Accordingly, policymakers must address AVs in a responsible and well-thought out manner that will guide them to their full potential while also maintaining the interests and safety of all road users.

I. Introduction

In recent years, advancement in technology has begun to alter the way people and goods travel. One innovation that has the greatest potential to upend traditional travel is the automation of driving. Automated vehicles (AVs) could completely transform mobility networks, dramatically improve safety, reduce emissions, and provide access and mobility to underserved parts of society.[1] The proliferation of AVs could also lead to more suburban sprawl, congestion, greenhouse gas emissions, and higher household costs.

Although fully self-driving vehicles are not yet on the market, there has been significant technological progress on automated and semi-automated driving features for cars and trucks in recent years. Some automated features, such as lane centering and adaptive cruise control, are available on vehicles today. Although there is much speculation about when exactly fully automated vehicles will see widespread deployment, there is no question about the impressive speed of recent development.

Meanwhile, the emerging AV industry is asking policymakers to adapt frameworks to address the demands of automated vehicle sales and ensure U.S. competitiveness in the global market.[2] This includes updating regulations, funding research and development, and investing in infrastructure. Creating a policy and investment plan that adapts to a changing environment poses significant challenges for public officials. Yet it is important to consider the policy implications for AVs now, given that self-driving test vehicles are already sharing public roads with drivers.

This paper discusses the current and future state of AVs, and the implications for policy at the federal, state, and local levels. It does not intend to summarize all the research nor provide new analysis of the potential implications of AVs. The goal is to provide concrete and substantive recommendations for policymakers in order to responsibly deploy AVs on public roads.

II. Understanding AVs Today

Today, an increasing number of features on vehicle models are automating the driving task.[3] These include:

1. Adaptive cruise control, that automatically adjusts vehicle speed to maintain a safe distance from vehicles ahead;
2. Lane centering systems, that automatically ensures a vehicle stays in its lane (unless a turn signal is on in that direction) and/or warn a driver when they veer out its lane;
3. Preemptive braking systems, that automatically slows a vehicle when a human driver does not detect an emergency;
4. Parking assist systems, that allow vehicles to maneuver themselves into spaces;
5. Systems that combine one or more automated features to steer, accelerate, and brake on certain roadways under human driver supervision. This feature is currently offered by a select number of manufacturers such as Mercedes, BMW, Tesla, Cadillac, and Lexus;[4]
6. Technology that monitors the driver, such as hands-on-wheel sensors and/or driver gaze observations to prevent distracted operation.

These features correspond to a specific "level of automation" on the National Highway Traffic Safety Administration (NHTSA) classification system for AVs.[5] That system, which was adopted based on the Society of Automotive Engineers (SAE) International classifications, defines six different levels of vehicle automation referenced throughout this paper (Table 1).

Table 1: Classification System for Vehicle Levels of Automation

Level	Name	Automated System Role	Human Role
0	No Automation	None	All driving functions of the vehicle
1	Driver Assistance	Features such as adaptive cruise control or lane centering to independently assist the driver	Responsible for all core driving functions
2	Partial Automation	Conducts some parts of the driving task, such as steering, acceleration, and deceleration	Responsible for monitoring the external driving environment and ready to take control with or without warning from the system
3	Conditional Automation	Performs most driving functions and monitors the driving environment. May request human driver to intervene for specific driving tasks	Must remain ready to take control and respond appropriately to the AV systems' request to intervene
4	High Automation	Conducts all driving tasks and monitors the driving environment. However, can only operate in certain environments and designed for specific situations, such as a defined route shuttle. No steering wheel, pedals or shifting mechanisms required for a human driver	Human is present but does not need to take back control
5	Full Automation	Conducts all driving functions under all environments without a human driver	Human provides destination or navigation input but does not control the vehicle at any point. Designers may include features such as steering and speed control to allow human operator when system is not engaged

Source: Adapted from SAE Levels of Automation — *Created by: Ann Henebery / Eno Center for Transportation*

Table 2: Expected Commercial Availability of Level 3 or Higher Vehicle Automation, by Select Organization

Organization	Year	Type of Organization	Automation Level
Ford Motor Company	2021	Vehicle Manufacturer	Level 4
Uber	2021	Transportation Network Company	Unspecified
Volvo	2021	Vehicle Manufacturer	Level 4
General Motors	2020	Vehicle Manufacturer	Unspecified
Tesla	2018	Vehicle Manufacturer	Level 3 or 4
Google	2020	Technology Company	Level 4
Victoria Transport Institute	2020-2030	Research Organization	Unspecified
National Association of City Transportation Officials	2020	Association	Level 4
IHS Markit	2020	Market Research Company	Level 4 and 5
ABI Research	2021	Market Research Company	Level 4 and 5
Juniper Research	2025	Market Research Company	Unspecified

Source: Endnotes 10 – 20. *Created by: Ann Henebery / Eno Center for Transportation*

Level 1 vehicles are in wide use today. Level 2 capabilities are available on several luxury car brands, such as Tesla, Mercedes, and Cadillac. There are no market-ready vehicles at Levels 3, 4, or 5 as of the publication of this paper. As they become available, these vehicles will be equipped with automated driving systems (ADS), and will be capable of performing all dynamic driving tasks (steering, accelerating, signaling, braking, etc.).

Table 2 shows that there are diverging opinions on how these will reach the market. Some industry leaders believe AVs will be market-ready in less than five years.[7] Other companies and researchers recognize that there needs to be far more testing and relevant policies or regulations.[8] For example, the director of Duke University's Humans and Autonomy Lab notes that AVs are "absolutely not ready for widespread deployment."[9]

AVs: Personal vs. Shared

The rapid development of AV technology has already started shifting the business models of automotive mobility. Some developers are focusing their initial deployment efforts around a shared fleet of vehicles rather than individual ownership. Examples include Uber's deployment of self-driving fleets in Pittsburgh, Tempe, and San Francisco; and General Motors's (GM) financial partnership with Lyft. To recover their significant development costs, firms could charge for automated driving services rather than selling a one-time product. This model could upend how consumers interact with the technology. Additionally, this approach will allow companies to not only retain control of the vehicle for necessary maintenance, but would also allow for a distrustful general public to become more comfortable with the technology.[6] Policymakers need to consider both models as they plan and develop future laws and regulations around AVs. The recommendations in this paper can apply to both the private and fleet ownership models.

As with many new technologies, the market and the public often have inflated beliefs of what will occur once the technology is mainstream. Therefore, the hype surrounding AVs should be a caution to government agencies looking to make large investments in policies and resources. This matters because although AV technology has taken a giant leap forward in recent years, its policy development goes back several decades.

One of the first major public investments in self-driving technology came in 1991 when Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA). That law authorized $650 million to develop technology necessary for driverless cars to operate on an automated highway. The early renderings of a driverless system imagined "smart *infrastructure*", with roadways and vehicles outfitted with sensors and hardware that would guide an automobile along a programmed path. The culmination of this endeavor was a 1997 demonstration of a vehicle test fleet with operators not using hands or feet driving 7.6 miles of Interstate 15 in San Diego.[21]

While the technology worked successfully the ambition of achieving driverless cars through smart infrastructure was never realized on a broad scale. Much of this is due in part to the massive, coordinated public and private sector investment that would be needed to outfit millions of miles of roadways and millions of vehicles.

Today, AV technologies are rolling out because of this improved system powerful enough to create "smart *vehicles*" that drive without the need for exterior input or special infrastructure. Federal efforts that supported sophisticated research and development such as the U.S. Department of Defense Advanced Research Projects Agency's (DARPA) Grand Challenges (beginning in 2004) and its Urban Challenge (in 2007) played a key role in catalyzing the development of self-driving vehicle technologies, companies and workforce.[22]

The smart vehicle approach leaves governments with a supporting role in the development of AV technologies. However, the resulting policy vacuum has left companies uncertain about "the legal environment that awaits their new vehicles."[23] Firms developing AVs are worried about a patchwork of state and local rules which could thwart the testing and sales of certain types of driverless vehicles across jurisdictions.[24]

In response to increasing demands for federal guidance, NHTSA released its Federal Automated Vehicles Policy Statement (FAVP) in September 2016.[25] The statement was written in consultation with industry stakeholders including automakers, tech firms, state government officials, and experts in the field. While the FAVP is neither binding nor comprehensive, it establishes a foundation for industry leaders and the federal government to collaborate on developing AV policies.

The FAVP sought to assuage industry concerns surrounding the lack of regulatory certainty for AVs. It provides guidance to manufacturers testing and developing AVs on public roads, clarifies the roles of the federal and state governments in regulating operations and outlines NHTSA's existing and potential enforcement mechanisms. NHTSA received over 1,000 formal comments and will update this document in the coming years.[26]

The first section of the FAVP is titled Vehicle Performance Guidance for Automated Vehicles. It lists best practices for safe pre-deployment design and testing of AVs prior to eventual commercial sale or operation on public roads. NHTSA highlighted its expectations of the industry, including a set of voluntary practices and procedures. The central feature of this section is a 15-point safety assessment letter (SAL) that NHTSA requests manufacturers submit. The SAL covers issues ranging from crashworthiness to ethical consideration to vehicle cybersecurity. NHTSA stated that it expects manufacturers to submit SALs at least four months before active public road testing begins on new automated features. The agency also requests that manufacturers submit a new Safety Assessment when they perform significant AV updates. The SAL includes Level 2 vehicles along with higher levels of automation, meaning that SALs technically apply to vehicles already on the roadway.

The second part of the FAVP is the Model State Policy. It delineates the federal and state roles in regulating the certification and regulation of AVs. NHTSA discourages states from regulating the design and performance of AVs, which is the responsibility of the federal government. States are preempted from establishing motor vehicle standards that are not identical to existing Federal Motor Vehicle Safety Standards (FMVSS) regulating the same performance aspect. Instead, NHTSA recommends states focus on their core responsibilities of licensing human drivers, registering motor vehicles, enforcing traffic laws, and regulating motor vehicle insurance and liability.

In the third section, NHTSA's Current Regulatory Tools, the agency reiterated its role in regulating vehicle safety. It discusses how NHTSA can use exemptions, rulemakings, defects enforcement and other tools as they apply to AVs. The agency stated that it would work with automakers to facilitate the safe testing and deployment of AVs by issuing letters of interpretation to help manufacturers understand existing laws, issue exemptions to existing FMVSS, conduct notice-and-comment rulemakings, and leverage its investigative authorities to identify safety defects and issue recalls. For example, current regulations allow manufacturers to request general exemptions in order to temporarily test and deploy vehicle designs that do not comply with existing FMVSS. Manufacturers can use these exemptions on AVs and apply for one to allow for provisional operation on public roads for anywhere from 2,500 to 10,000 motor vehicles per manufacturer, contingent on the type of exemption. In the short run, automakers suggest this would allow them to deploy AVs as quickly as possible but they have also begun urging Congress to raise the caps on exempted vehicles.[27]

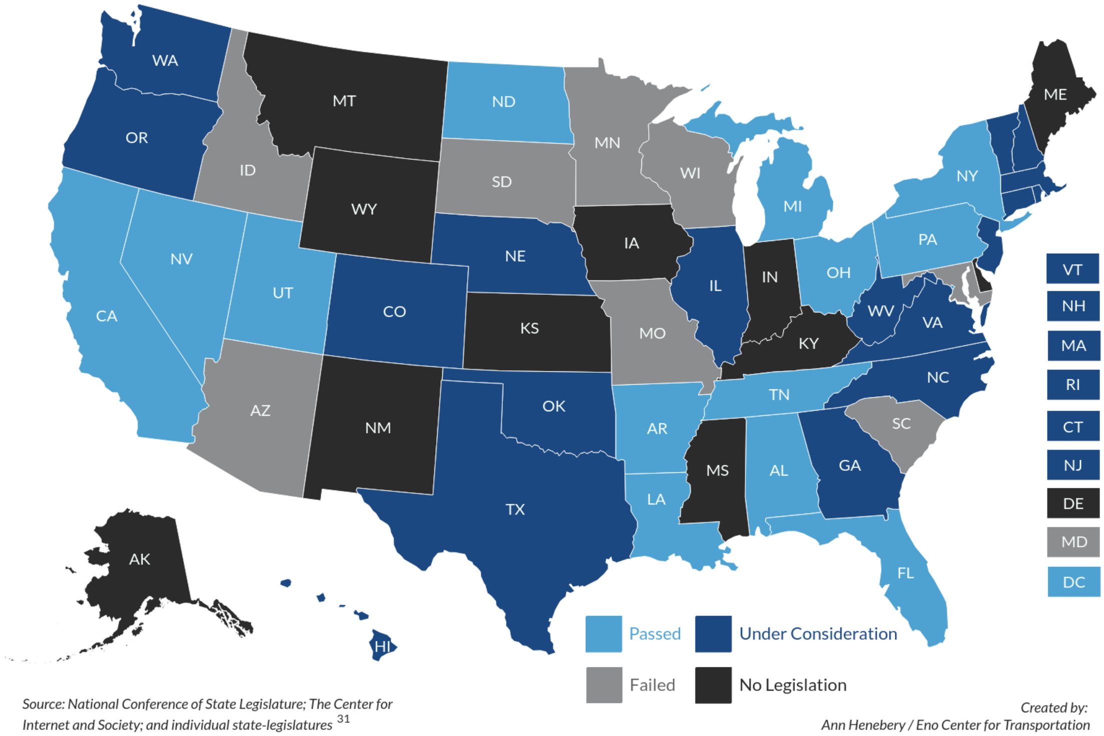
The final section, New Tools and Authorities, outlines new ways for NHTSA to use its regulatory tools and authorities to encourage safe AV testing and deployment. One of NHTSA's priorities is to conduct and contribute to research that will allow the government and manufacturers to measure the safety and performance of AVs. Developing these research metrics will permit the agency to quantitatively assess the risks and benefits of AV systems, ultimately aiding in the development of FMVSS regulations. The agency refrained from advocating for, or voicing opposition to, using their regulatory authorities to expand exemptions for AV fleets and increase hiring authority to employ more subject matter experts within the department. Instead, NHTSA requested comments from industry and the public on how the agency could ensure the safe deployment of AVs without stymieing innovation.

The AV industry's reactions to the FAVP fall into three general categories. The first is a disagreement with the inclusion of Level 2 vehicles in the SAL, which SAE does not categorize as "Highly Automated" (see Table 1). Level 2 vehicles are already operating on roads today, creating confusion as to who should submit SAL for that technology and when. The second concern is with the SAL itself. For NHTSA to evaluate the letters, AV developers would need to disclose propriety information about their system design to federal regulators. This would include trade secrets and other confidential data that could be subject to public access. The third major concern is with the FAVP's implied recommendation that states formally adopt the NHTSA policy, rendering the voluntary guidance compulsory. Writing a SAL for each state would be burdensome to AV developers and, they claim, not very productive for safety.[28]

States have started to take action to more clearly define requirements, regulations, and investment schemes that address major AV issues. As of April 2017, thirty-nine states and the District of Columbia have proposed or enacted self-driving laws (Figure 1).[29] This is resulting in a patchwork of state regulations, which troubles many AV developers, even while different laws provide important lessons for shaping future federal and state policy.

The first state to enact legislation authorizing the operation of AVs was Nevada in 2011. The law defined "autonomous vehicles" and directed the state's department of motor vehicles to adopt rules for license endorsement, operation, insurance, safety standards, and testing.[30] Since then, thirteen states enacted AV legislation: Alabama, Arkansas, California, Florida, Louisiana, Michigan, Nevada, New York, North Dakota, Ohio, Pennsylvania, Tennessee, Utah, as well as the District of Columbia. Twenty-six others introduced legislation relating to AVs that either did not pass or is still pending as of April 2017.

Figure 1: Status of State Legislation Related to Automated Driving, April 2017



The laws vary in scope, rules, and extent, and are creating a medley of state frameworks to which AV pilots must adapt. For example, Florida simply sets the definition of an automated vehicle and permits their operation. North Dakota established a legislative management study of AVs, and Utah authorized its state department of transportation to conduct a testing program for platooning vehicles following at close distances.[32] Tennessee sets up a framework for the state to begin charging a per-mile fee on AV driving. Recently, Michigan passed the most comprehensive AV legislation that allows for testing on public road without a driver, truck platooning, and legalized self-driving ridesharing in the state.[33]

Other states have used the executive branch to initiate piloting of AVs. Both Massachusetts and Arizona governors issued executive orders to establish pilot procedures in their respective states. In Arizona, the governor issued an executive order for various agencies to support the testing and operations of AV and encouraged universities to launch pilot programs for AVs.[34] The Massachusetts directive created an AV working group to craft legislation and a Memorandum of Understanding (MOU) agreement for companies to enter into for testing on state roads.[35]

Attempts to harmonize AV regulations are not limited to the United States. The United Nations 1968 Vienna Convention on Road Trafficking harmonizes Europe's regulations for use of roadways, and the UN is working to update that code to allow for AV technologies.[36] Australia's National Transportation Commission published national guidelines on AVs in an attempt to establish a consistent regulatory environment across the country.[37] The size and concentration of AV development in the U.S. market demands interstate and international cooperation. While it is beyond the scope of this paper to fully examine international efforts on regulatory harmonization, policymakers will eventually need to consider the global AV market when designing and developing regulations.

III. Implications and Recommendations for Policymakers

With so much uncertainty regarding AVs in terms of their specific capabilities and timeline, policymakers need to take an approach that is performance-based and enables responsible AV deployment regardless of when or how the technology eventually takes shape. These policies should be focused on creating an environment where firms can deploy technologies that provide benefits to society and consumers, while also protecting the general public interest and welfare.

The following recommendations address some of the most important areas of AV policy, and can help guide safe, efficient, and sustainable deployment.

A. Certification, Liability, and Insurance

For policymakers, the issues that surround how to certify automated driving systems (ADS), assign liability for collisions, and insure against damages in a driverless or quasi-driverless world are some of the most challenging. For instance, driving liability currently applies to the operator of the vehicle, which has always meant the human behind the steering wheel. Now, experts are suggesting that this risk should shift from the human driver to software developed by the vehicle manufacturer and technology providers.[38]

There is not yet a precedent where the automated system has been held liable for a crash. States have long governed product liability, but without uniformity from state tort laws or consistent and updated regulations from the federal level, AV companies do not know the answers to crucial questions about the liability for use of their products. Further, insurance providers may not know whom to hold liable for accidents. A shift in driving responsibility calls attention to the need for more clarity in the legal framework.

In most cases, the assignment of responsibility—and therefore liability—is straightforward. For example, when driving under Level 1 automation, which includes cruise control that exists on most cars, the human driver is clearly responsible for driving the vehicle. The opposite is true at the other end of the scale: in Level 4 or 5 automation the driver is not responsible for intervening and taking back responsibility in any case.[39]

The problems arise in Levels 2 and 3. In these cases the automated driving features can maneuver the vehicle in most instances, but require the human driver to ultimately be in control. In Level 2, where the system conducts both steering and acceleration/deceleration functions, the driver is expected to continually monitor and is responsible for the system's performance while engaged (unless the system forces this through driver monitoring such as hands-on-wheel sensing and/or driver gaze monitoring). For example, if the system does not detect a problem in the roadway, it is the human driver's responsibility to take control immediately and avoid the crash. In Level 3, the vehicle's driving system is monitoring the environment, but if it detects a scenario that it cannot navigate, it warns the human driver and control is transferred back to the human.

Monitoring and scanning a roadway while traveling at high speeds requires focus, attention, and short-term memory, even for routine driving situations. A recent study found that the average person needs at least 17 seconds to regain full focus of a roadway environment before they are ready to regain control of a vehicle.[40] While that study had a small sample size and therefore is not conclusive, the findings clash with the expectation of Level 2 and 3 responsibilities. Recent observations of how humans act behind the wheel of Level 2 vehicles (such as Tesla's Autopilot feature) indicate that it is easy to lose focus.[41] A news article from early 2017 reported that the Ford Motor Company recently found their engineers routinely falling asleep during testing, despite alarms designed to keep the trained professionals alert.[42] Ford refuted this claim, but the company did note that high level automated driving does provide a "false sense of security" and represents a conundrum for the industry.[43] The system driving functions perform remarkably well in many cases: AV's track record indicates that its automated system drives the vehicle much safer than humans do.[44]

The first documented fatality in a Level 2 quasi-automated vehicle in the United States occurred in May 2016 when a Tesla Model S traveling at 65 miles per hour with "beta" Autopilot system activated crashed into a tractor-trailer. Tesla has stated that Autopilot failed because the system did not distinguish the white truck from the bright sky.[45] NHTSA conducted an investigation into Tesla's automated emergency braking technology and could not identify any safety related defects with the system. This finding cleared Tesla of any fault for the incident. The current framework requires human drivers of Level 2 vehicles to continuously monitor the driving environment and take over at a moment's notice, something that the driver in this incident did not do.

Critics of AVs argue that the Tesla crash proved that the technology is not yet ready to be deployed, despite evidence that AVs are much safer than human drivers.[46] For human drivers, there is a fatality for every 94 million miles driven. Tesla's "Autopilot" had its first fatality after 130 million miles of operation and has since added a billion miles without a death.[47] Furthermore, researchers found that Tesla's self-driving technology has reduced crashes by almost 40 percent for those vehicles.[48] In another example, the 2013 Honda Accord issues an audible warning when it gets too close to traffic ahead or leaves a lane without signaling. This has resulted in a 14 percent reduction of insurance claims for damage to other vehicles, a 40 percent decrease in bodily injury claims for other road users and 27 percent decrease in medical payments for owners.[49] However, according to a RAND study, AVs need to drive "hundreds of millions of miles" of miles, to definitively prove they are safer than human drivers.[50] The Insurance Information Institute states, "there will still be a need for liability coverage, but over time the coverage could change…as manufacturers and suppliers and possibly even municipalities are called upon to take responsibility for what went wrong."[51]

At the federal level, NHTSA stated that it legally defines a vehicle's driver as whatever—as opposed to whomever—is doing the driving.[52] But federal regulations still require all vehicles to have hand and foot-controlled brake pedals and parking brakes.[53] NHTSA's new guidelines provide auto manufacturers with the option to design a vehicle without these constraints, but they need to receive an exemption from the FMVSS (per Title 49 of the Code of Federal Regulations, Part 555), which is limited to 2,500 vehicles.

States are starting to lay a legal and liability framework to address AVs. For example, California proposed a rule in 2015 that would require AVs to have manual controls and a licensed driver in the vehicle, indicating consistent reliance on a human controller and implying that liability will stay with the *human driver*. However, this requirement poses a conflict with many technology firms' goal to eventually have fully self-driving vehicles without steering wheels or any manual controls at all. The proposed rule, which is currently in draft form, was revised to allow AV developers to test vehicles without a human driver provided they receive a permit from the state.[54] In 2016, Florida passed the first legislation that legalizes fully automated vehicles on public roads without a driver being present. It indicates that Florida intends the *self-driving technology* to be liable in the case of an accident.

A.1 Congress should pass legislation allowing NHTSA to issue system certifications to the technology in self-driving vehicles.

AV developers are designing their products to drive themselves on roadways across the country. Therefore, NHTSA, not individual states, should be responsible for certifying the technology used to drive them. The certifications assigned to automated driving systems will require specific standards that change for the level of automation. This system will apply whether an individual owns the vehicle or the vehicle is part of a fleet.

Technology-driven vehicle certifications can be temporally or geographically limited or could allow for operation anywhere, anytime. Regardless, in order for the technology to become certified, AV firms need to demonstrate to NHTSA that their technology is at least safer than a human driver in the type of environment that they are authorized to drive.[55] This certification process is necessary to protect other users of public roadways.

AV ADS certifications should be directly related to the NHTSA levels of automation. These levels make a distinction between who is ultimately in control of the vehicle, and correspond directly to the liable party in an event of an incident (see Table 3).

1. **Level 0 and 1**: Traditional human driver licensing requires the driver to be alert and in control of the car at all times when using features such as adaptive cruise control, lane assist, and electronic stability control. Under these circumstances, the driver is the one who is licensed, and thus ultimately responsible and liable for the control of the vehicle. Most cars will be Level 0 and Level 1 for many years to come so there should be no change to the current licensing or liability arrangement.
2. **Level 2:** Requires that the human driver has the role of supervising the ADS in real time and intervening, with or without warning, as needed to maintain safe vehicle operation. As a matter of safety, Level 2 features must include a driver monitoring and enforcement

system that ensures that the driver continues to supervise and monitor the environment. The technology developer need not fully certify its ADS system, but it must demonstrate that it can safely deny system operation if the driver appears to be losing focus.

3. **Level 3:** NHTSA must fully certify all Level 3 driving systems and create a standard warning time for the transfer of control from the ADS to the human driver. Under Level 3, the ADS controls all aspects of driving with the expectation that the human driver will respond appropriately upon a system's request to intervene. Preliminary studies and anecdotal evidence indicate that human drivers, even those with extensive training, lose focus easily in Level 3 test vehicles, and require a period of transition time to fully regain awareness.[56] NHTSA needs to conduct a comprehensive analysis that determines the appropriate amount of time required for a human driver to regain focus. The agency should then make that the minimum amount of time that a Level 3 vehicle needs to give to its human driver upon request to intervene.
4. **Level 4 and 5:** NHTSA must fully certify Level 4 and 5 driving systems. This should also include any remote-controlled operation of vehicle. There does not need to be a licensed human driver in the car if operating in its certified driving environment.

Table 3: Certification Levels for Automated Driving Systems (ADS)

Level	Name	NHTSA AV Certification System
0 – 1	No Automation/Driver Assistance	Licensed human driver required to be alert and operate vehicles at all times.
2	Partial Automation	Licensed human driver is responsible for supervising the ADS system at all times. The system must include a driver monitoring or awareness feature and certify denial of service if operator loses focus.
3	Conditional Automation	NHTSA must certify the ADS, which controls all aspects of driving with the expectation that the human driver will respond appropriately upon a system's request to intervene. NHTSA must define a safe transition time when the ADS disengages.
4	High Automation	NHTSA must certify ADS for all driving functions within respective operational environment.
5	Full Automation	NHTSA must certify the ADS can operate in all places and all environments.

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Certifying AV technology with these performance metrics and standards should preempt the patchwork of state laws that manufacturers and tech firms currently navigate. While the certification system is currently built around the adopted SAE levels of automation, NHTSA should be open to alternative distinctions between drivers and AV technology as the certification process evolves.

During the initial certification process, it will be important for NHTSA to work with AV companies to address issues with version control of software, over-the-air updates, and ultimately recertification. As NHTSA has historically overseen regulations around hardware and manufacturing, the certification process for AV software will require the right balance of technical expertise and flexibility to accommodate new designs and updates. If the vehicle owner declines to update software, repair ADS sensors, or fix other components, the AV system can lock itself and prevent it from being used. As with conventional vehicles, states will remain responsible for licensing of human drivers, registering vehicles, and enforcing the safety of the roadways.

Certification for safety in transportation is not new to the federal government. The Federal Aviation Administration (FAA) certifies aircraft and aircraft parts, and could be a useful example of how NHTSA can approach AV certification.[57] But while FAA certification is broader in scope, including everything from structural integrity to avionics, AV certifications would focus on the vehicle and software. The FAA's certification process illustrate that it is a dynamic function and the agency continually works with the industry to improve the process. FAA's most recent certification reforms include risk-based performance standards that prioritize the safety outcomes over deterministic approaches. While it is outside of the scope of this paper to fully examine the exact process of AV certification, lessons about dynamic and performance-based approaches to safety are important for NHTSA to consider.

A.2 NHTSA should support the harmonization of state tort laws that explicitly align liability with the certifications and roles of the ADS and the licensed human driver.

In each case discussed previously, the liability corresponds to the human or level of automation that is assigned to a dynamic driving task. With crash liability, traditionally a role of state governments, NHTSA should work with national organizations to help all 50 states and the District of Columbia update and define their tort laws for automated driving. This would help ensure that insurance requirements are similar for human drivers and technology firms during their respective durations of control.

A.3 States should create stakeholder working groups to oversee the development of laws.

If poorly designed or inconsistent with neighboring states, AV regulations at the state level can do more harm than good. Such laws do not necessarily guarantee safer AVs, nor will they necessarily attract significant AV developer investment. Most states do not have any regulations or laws regarding AVs. While not passing state AV laws leaves any AV subject to existing traffic and motor vehicle regulations, it does not explicitly prohibit testing, provided there is a human driver in the driver's seat. These states are not unaware of the changing environment, but instead are waiting to see how the market evolves in the rest of the country and how more proactive states react.[58] Current laws exist to protect public safety, and that does not change under AVs.

A stakeholder advisory group should consist of policymakers, regulators, lawyers, private AV developers, trade groups, community groups, environmental groups, and others that have a direct stake in the policy outcomes for AVs. The group should meet regularly—perhaps two to four times annually—and should provide guidance to policymakers on how to best integrate federal regulations with existing state laws in a rapidly changing technological environment.

B. Cybersecurity and Data Ownership

The rise of AVs and connected vehicle technologies raises two concerns with respect to data and cybersecurity. The first relates to who owns the massive amount of data collected during AV operation. The second involves malicious access to driving systems and what could result from such an attack.

In terms of data ownership, there are multiple parties involved that might want access to data collected by the vehicle, including the automaker, the technology developer, the human occupant, urban planners, and the vehicle owner. Some of this data is extremely valuable to businesses, such as mapping data, traffic data, and personal information about where the driver travels and spends money.[59] Operational data could also determine fault in the event of an incident, providing police and injured parties with a detailed analysis of an accident. New vehicles are already equipped with event data recorders (EDR) that provide operational information when involved in a crash with standardized data reporting requirements. Current laws state that all EDR data belongs to the vehicle owner and can only be accessed with consent or through a court order.[60] However with AVs (depending on the ownership model) it is unclear who owns what and who has the legal access to the information in question. The National Association of City Transportation Officials (NACTO) advises that the federal government explicitly define exactly who owns what data and in what scenarios they are required to share it. [61]

In some cases, driving software could be illegally accessed and repurposed to cause crashes. An example of car hacking made news in July of 2015 when two "white-hat hackers" (professionals who break security in order to expose weaknesses) remotely disabled a Jeep's engine and brakes.[62] Although Fiat Chrysler Automobiles has since addressed the vulnerability, this could become a greater danger as more vehicles have outside digital connections. Other potential disruptions include signal jammers and other types of interference that disable or confuse the sensors on the car. Disrupting signals on a busy stretch of highway or in a dense urban area could have catastrophic effects.

To address emerging threats and vulnerabilities with AVs, the automotive industry launched the Automotive Information Sharing and Analysis Center (Auto-ISAC), a non-profit that is enabling the sharing of cyber threats and vulnerabilities across its membership.[63] In January 2016, the organization released a set of guidelines for technology developers to increase the safety of their systems.[64]

In late-2016, NHTSA released voluntary guidance for technology developers on cybersecurity for modern motor vehicles.[65] The recommendations cover areas that AV developers need to focus on during the design process, such as secure development practices, information sharing, disclosures of vulnerabilities, incident response, and self-auditing. The guidelines reiterate the fundamental cybersecurity precautions that emphasize restricting access to critical components in connected vehicles and establishing strong boundaries between the vehicles communications and driving systems.

B.1 NHTSA should explicitly define that the ownership of the vehicle's data corresponds to the operator of the vehicle.

Vehicle manufacturers or AV technology firms should retain ownership of the data produced in the vehicles during any operation when their sensors are collecting data. But private firms must be required to share that ownership with a human operator if s/he is in control of the vehicle at the time of a crash. For example, if a Level 2 driving technology expects the driver to be liable in the case of a crash, then the data must be fully shared between the technology firm and the car owner. However, if an AV is liable for a crash, and the human occupant is not expected to have any driving responsibility, then the technology firm would exclusively own the data. If an incident occurs on a public roadway, companies should be required to provide data to government and law enforcement officials to prove fault in the case of a crash or other incident where there is loss of property or personal injury.

B.2 Congress should explicitly require the AV industry to protect the privacy of vehicle owners.

Manufacturers must protect the privacy of the vehicle owners and companies should not be allowed to distribute personal identifiable information about vehicle owners or occupants without their approval and knowledge. Consumers should be informed of these data ownership rules prior to car purchase.

B.3 Congress should define AV developers' limited liability for crashes that result from a security breach.

If there is a breach to a personal computer or corporate network, there may be a loss of personal information, financial data, or corporate trade secrets but likely not their life. Hacking into vehicles could be disastrous for safety. It is impossible to create a system that is un-hackable, and any security breach of an AV system is a crime. But given the seriousness associated with hacking, holding AV developers accountable to securing their systems is important for public safety and ensuring consumer acceptance.

NHTSA took an important first step in establishing federal guidelines to secure connected vehicles and protect drivers' privacy.[66] But to ensure that AV tech firms are taking cybersecurity seriously, they should be held liable in the case of an accident caused by a security breach. Legislation is needed to certify requirements for insurance to cover any security breaches that cause physical or financial harm. This should help provide that a minimum standard is met and that the tech firms self-police, as they would be ultimately liable for a breach. As new updates to software becomes available, manufacturers should be allowed to update over the air or require vehicles to be serviced immediately for safety concerns, or they could disable the semi- or fully-automated features until the consumer updates or fixes the vehicle. If a vehicle owner declines to update or fix their vehicle, then the AV developer should deny them AV services.

B.4 Cities and states should establish data sharing agreements to enhance local transportation planning and operations.

AVs need public roads on which to operate, and the agencies that manage traffic and conduct maintenance on these roads can greatly benefit from a wealth of travel information from the vehicles that use them. Data sharing agreements would provide beneficial updates on road conditions and traffic flow to drivers and agencies. This data needs to be scrubbed of personally identifiable information and information that could provide a competitive disadvantage to the technology firm, but can be used to improve planning, emergency response, and congestion mitigation. Data sharing can be an important way of improving infrastructure and AV operations to yield greater public benefits.

B.5 States and cities should update laws that prohibit and punish any deceiving or disabling of AV communications.

States should update their laws to prohibit mischievous or nefarious activities that can interfere with the safe operation of AVs. This can encourage an environment for safe AV testing and eventual deployment, and in the meantime, make roadways better and safer for all road users. With the number of testing centers across the county growing, state and local departments of transportation should begin to work closely with them to identify necessary updates of traffic laws that optimize the roadway for safe mobility regardless of travel mode.

C. Infrastructure and Funding

Even if AV technology is perfected, driverless cars still face another hurdle: the built environment. Given that current roadways, intersections, and signage were built to accommodate human drivers, pedestrians, and cyclists, this infrastructure needs to adapt to make all roadway users safer.

For example, a predictable driving environment, such as well-marked traffic lanes, is necessary for current AV technology, so cities and states need to improve lane striping and signage. Construction workers and emergency vehicles could communicate with AVs via a smartphone app or some type of wireless signal, rather than using hand gestures or sirens and flashing lights.[67] Traffic signals may need to be reconfigured to either communicate wirelessly to approaching vehicles or to ensure that, no matter the position of the sun, AVs can view and register the traffic light.

Improving roadways to better accommodate AV technologies poses significant costs, which is challenging especially for cities and states already struggling to upkeep infrastructure. Whether it is better roadway conditions or advanced sensors and transmitters, the upgrades could cost states and localities millions or billions of dollars in repairs and upgrades. At the same time, full AV deployment may reduce revenue streams such as parking fees and traffic fines that help pay for such upgrades or fund other public expenses.

C.1 Congress should develop a per-mile charge fee system on vehicles that are operating with a non-human certification.

The direct infrastructure costs associated with the operation of AVs presents a unique funding need. Conveniently, AV technology also opens up an opportunity to implement a fair and straightforward per-mile charge or vehicle mile travelled (VMT) fee. Unlike traditional car purchases where there is an initial vehicle sale and little business interaction afterward, transportation today is more often being sold as a service.[68] The computerization of driving will require constant updates and refinements to ensure that vehicles can operate in an ever-changing environment. If regulations require the computer to be liable for driving incidents and security breaches, companies will want to ensure that they can recover those costs and the cost of enhancements to their software. Recent partnerships between auto manufacturers and transportation network companies (TNCs) such as Uber and Lyft, point to a future where tech firms will be selling Levels 3, 4, and 5 driving as a service, charging by the mile or by the trip. All this indicates that companies are laying the groundwork for a per-mile charge, and governments could take advantage of this to fund public infrastructure investments.

Given that the technology is nascent and limited to advanced or luxury features, now is the time to implement a system that can be used to support future infrastructure programs. Congress should establish a VMT-based charge on AVs that the U.S. Department of Transportation (U.S. DOT) would oversee. The fee could charge by mile and be designed to account for differences in vehicle types and other variables. Although it is a revenue stream from the user, manufacturers or tech firms should pay the VMT charge to the government (not the driver or car owner) and only for the portions of the trip that are completed under automated operation.[69]

At the start, the VMT rate can be set at a nominal $0.01 per mile. This small charge will not dissuade early adopters, and Level 1, Level 2, and test vehicles should be exempt. In fact, the $0.01 per mile rate is similar to the federal fuel tax rates. Current federal fuel taxes raise approximately $34 billion annually, and if all vehicles paid a $0.01 per mile fee, the net receipts would be $32 billion.[70]

The VMT charge may not create a particularly robust revenue stream at first, but could net about $318.6 million annually if 1 percent of all driving is done autonomously.[71] The monies should be used for a new federal grant program on transportation infrastructure and targeted to investments that improve the safety and reliability of AVs, including state of good repair programs and connected infrastructure deployment. In the future, this pricing could be indexed, supplemented by additional state fees (much like the current fuel taxes), and varied based on vehicle type. For example, the cost of a light duty vehicle on a public road is different than that of an 18-wheeler and the VMT fee structure could allow for fair collection to accommodate these differences. Policymakers need to be mindful of market distortions related to a VMT fee, and should consider offering discounts or other incentives to encourage the beneficial adoption of AV technology.

Work on a VMT fee has already begun: Oregon started a pilot project to test the replacement of its state gasoline tax with a VMT fee.[72] In 2016 Tennessee passed a law that would specifically charge a VMT for AVs. Although it has yet to be implemented, the revenue generated from the charge would be allocated to state, county, and local governments' transportation funds.[73] The federal government's 2015 Fixing America's Surface Transportation (FAST) Act set aside $95 million for VMT research.[74] The U.S. DOT can use this money to begin testing a VMT fee system for AVs before they become more prevalent on the roadways.

C.2 States and localities should invest in robust "state of good repair" programs that facilitate the semi-automated features already available on some cars.

States and localities own public roadways and have an important role in using limited public dollars to invest in infrastructure. Initial investment to assist AV development can be straightforward and easy to implement. Instead of smart or connected infrastructure investment [see Section D], states and localities can make significant improvements to their compatibility with AVs by simply improving the conditions of roadways. In addition to clear lane markings, pavement should be uniform and without potholes, traffic signals should be working properly and easily visible, and signs should be clearly legible and visible from the roadway.[75] Federal funding programs should encourage such investments, as it will benefit both AV and non-AV drivers.

D. Vehicle Connectivity

AVs and connected vehicles are closely related. Connected vehicles (CV) are those with the ability to communicate with each other (vehicle-to-vehicle or V2V) and with infrastructure (vehicle-to-infrastructure or V2I). Vehicle autonomy means that the vehicle can drive itself without connected input from its surroundings, but the combination of connected functions (known as vehicle to everything or V2X) can enhance vehicle automation. Many in the industry believe that AVs must be connected in order to speed the deployment and unlock the full benefits of driverless technology.[76]

CV technology communicates directly with other vehicles and infrastructure about vehicle data related to speed, location, trajectory, and other operational variables, potentially enabling better management of traffic flow with the ability to address specific problems in real-time.[77] According to the U.S. DOT V2X technology has the possibility to eliminate 80 percent of unimpaired crash scenarios that could save tens of thousands of lives each year.[78] But in order for V2X to work, there needs to be standards for communication and public sector investment in infrastructure.

In 1999, the Federal Communications Commission (FCC) allocated part of the electromagnetic spectrum for a system called dedicated short-range communication (DSRC). DSRC are close range communications channels that vehicles use to communicate with each other. But with the explosive growth of mobile and wireless devices, the current available spectrums are crowded and telecommunications providers have sought to expand into the spectrum currently reserved for connected vehicles. Despite recent progress, movement on CV technology has progressed slowly because it requires significant coordination and public sector investment. As a result, the wireless industry is now being pitted against the automotive industry on whether this allocation would jeopardize the safety of connected vehicles.[79]

U.S. DOT is currently piloting a CV program intended to understand how best to implement this technology in a variety of scenarios across the country.[80] New York, Tampa, and Wyoming are part of the study, which includes investments in V2I technology with technology-enabled cars. U.S. DOT has not yet completed the pilot, but it is offering a perspective into how signals and vehicles can be upgraded to communicate key information about roadway conditions. On December 13, 2016, the agency issued a Notice of Proposed Rulemaking to mandate DSRC communication technology in all light duty vehicles by 2023.[81] The rule would require CV technology in all vehicles, although it does not require the application of the technology nor does it explicitly state a standard to be used across all vehicles.

D.1 The Federal Communications Commission should maintain the existing spectrum for connected vehicles.

V2V and V2I communications are still in pilot phases and will require significant standardization and investment to become widespread. It is important to reserve the spectrum for these technologies as they develop alongside AV technology. Reserving the spectrum will prevent crowding of the existing network for CV and AV to use seamlessly. If other technologies, such as 5G wireless communications, become available and render the spectrum unnecessary, then the government can make it available for other uses.

D.2 NHTSA should continue to work closely with the automotive industry on standards for V2V and V2I communications.

In order to get the full benefits of connected vehicle technology, NHTSA and the automotive industry should continue to collaborate through industry organizations like SAE to set standards for V2X. This maintains a universal language for all vehicles to use, regardless of manufacturer (e.g., a Honda Accord must be able to communicate with a Ford Fusion). These standards should also address cybersecurity issues and other ways that vehicles can communicate safely and securely.

E. Federal Safety Programs

More than 40,000 fatalities and 4.6 million nonfatal injuries occur annually on U.S. roads.[82] Automobile collisions are one of the major leading causes of death in the United States, which has significantly higher car crash fatality rates than other high-income countries.[83] Of the thousands of traffic deaths each year, 94 percent are attributable to human error.[84] And while humans might drive while distracted, intoxicated, or fatigued, computers do not, and are capable of 360-degree awareness and much faster response times.[85]

NHTSA estimates that the federal government absorbs 4 percent of vehicle crash costs, with an additional 3 percent coming from the state and local level.[86] These include lost workplace and household productivity, traffic congestion, property damage, and medical costs, among others. Eliminating or reducing these could result in governmental savings of up to $10 billion each year.[87] The first step is requiring specific safety features on vehicles once the technology is ready, as well as making public investments to ensure that the technology functions properly.

E.1 Congress should make AV technologies eligible for federal safety programs to improve transportation operations.

States should have the ability to choose technological solutions to solve transportation safety problems, provided they can demonstrate the greatest improvement in crashes, injuries, and fatalities for the federal dollar. For example, to improve safety a state agency could straighten a dangerous curve for $50 million, or instead could invest in technologies that can increase safety through better lane markings or signaling systems that AVs could easily navigate. It is possible that technological improvements to roadway operations would be significantly less expensive and at the same time achieve greater safety benefits. In either case, the state should have the flexibility to meet safety targets through the most effective means.

F. Environmental Programs

AVs present an opportunity to expand mobility options, while reducing the environmental impacts of transportation. There are several ways that AVs could reduce congestion and emissions, thereby minimizing the negative impacts that automobiles have had on the environment. Traffic congestion is harmful to the environment: gasoline and diesel powered vehicles burn more fuel and emit more pollutants when moving slower and navigating stop-and-go traffic.[88] Programming AVs to drive more efficiently would yield smaller gaps between cars, more cars per lane, and smoother braking, thus easing congestion and energy usage. An entire fleet of AVs could operate as a coordinated platoon, and this smoothed traffic flow would increase fuel economy and decrease automobile emissions.[89]

AV deployment could also cut average ownership rates of vehicles. Some research indicates the number of cars per household could drop by 43 percent: from an average of 2.1 to 1.2 vehicles.[90] A report from the International Transport Forum discusses how a shared fleet of AVs—in combination with public transportation—could sustain current levels of mobility using only 10 percent of the cars.[91] To achieve this, AVs would be shared simultaneously by several passengers thereby reducing the need for private vehicle ownership and decreasing congestion. A 2016 study from the Frontier Group recommends utilizing driverless cars in ways that facilitate the use of shared mobility services, vehicle electrification, and smart pricing.[92] In this model, individuals would not own and use personal AVs but, instead, AVs would function like a fleet of self-driving taxis that can be hailed when necessary which could reduce the total vehicle miles traveled.[93] AVs also present a major opportunity for fleet turnover, thus an equally large opportunity to clean the nation's transportation fleet if the vehicles are electric.

Further, AVs offer a solution to parking and other urban problems that presently stem from widespread individual car ownership. One expert estimates that in many cities, up to 45 percent of the traffic is caused by people looking for a place to park.[94]A shared use model could make the search for parking easier thereby reducing greenhouse gas emissions.

On the other hand, AVs pose a potential threat to mobility and the environment. If Americans each buy a vehicle with inexpensive AV technology, research models estimate a 75 percent increase in individual vehicle usage.[95] That has the potential to not only clog existing roads and highways but also drive up transportation-related emissions. Driverless car owners might commute to work with their car and then send it back home, or shoppers may have their cars circle the block while waiting. This could lead to a substantial increase in VMT and congestion, potentially doubling the number of vehicle trips and increasing emissions.[96]

In the long run, Level 5 AVs would almost certainly create a transportation market for those unable to drive. By 2050, the elderly population in the United States will grow to 80 million people and—currently—80 percent of older drivers live in car-dependent suburbs or rural areas where they cannot rely on public transportation to get around.[97] Google made headlines when it released a video in 2012 of a blind man riding in a retrofitted Toyota Prius prototype and again when the same man rode in the company's newer prototype, a pod-like car without a steering wheel or brakes.[98] Parents may dispatch a driverless car to take their children to school or other activities. The scenarios could be a mobility benefit for those that have restricted access to transportation, but could potentially be detrimental to congestion and the environment if not properly managed.

F.1 Congress should create a federal transportation discretionary grant program that targets projects that meet both environmental and accessibility goals.

AVs have the potential to enhance mobility and decrease congestion, particularly in densely travelled corridors. Yet in the absence of environmentally-focused investments and policies, widespread use of AVs could lead to a large increase in VMT and sprawl, yielding even more congestion. Existing and future federal transportation programs must have defined goals aimed at reducing energy usage and pollution, while still growing our regional economies.

A federal grant program could competitively award funds to projects that employ technologies that both increase the efficiency of the economy while reducing the environmental impact. If states and regions are incentivized to reduce transportation emissions, AVs can be well positioned to play a positive role in meeting this objective. Examples of federal grant programs, like the U.S. DOT Smart Cities Challenge and Mobility on Demand Sandbox, should continue to encourage and incentivize state and local public agencies to work with the private sector to implement innovative approaches using AV technology on improving accessibility and environmental outcomes.

F.2 Cities, counties, metropolitan planning organizations (MPOs), and state Departments of Transportation should examine and include the potential impacts of AVs on regional transportation systems in their long-range plans.

Planning organizations play a critical role in designing and monitoring the long-term outcomes of regional transportation networks. As agencies develop long-range plans, they should work with policymakers and other stakeholders to identify how AVs help or hinder achieving their goals on accessibility, air quality, and land use development. For example, North Central Texas Council of Governments (NCTCOG) is hiring a transportation planner, who will largely be focused on planning the data and physical infrastructure needs for the introduction of automated vehicle technology in the North Texas region.[99] It is unclear when or how AVs will affect regional roadways or transit networks, but planners should consider how to incorporate AVs and mitigate some of their negative impacts.

F.3 States and cities should consider using pricing to mitigate negative externalities of AVs.

Research suggests that fully deployed AVs will make driving cheaper and easier, resulting in large increases in vehicle miles travelled. This could have detrimental effects on congestion, air quality, and suburban sprawl. For example, to avoid parking fees an AV owner could have their empty cars circle the block or even send them back home, essentially creating two additional trips.[100] While AVs can potentially increase mobility for many communities, state and cities should consider using pricing to incentivize more efficient usage.

Building on a per-mile AV charge [see Section C.1], state and localities could experiment with additional charges for AVs traveling without a passenger. Conversely, pricing could be applied as an incentive, for instance, in AVs operating with 2 or more passengers the car could be operate for free or at a reduced price. Varying pricing could create scenarios in which they not only discourage empty AVs but incentivize shared vehicles while reducing total vehicle miles traveled.

G. Research Investment

Private sector initiatives and university research have led the way in AV development, mostly through a mixture of public and private funding. These range from private tech companies like Google and Uber; to automakers like Tesla, Audi, GM, and Ford; to universities like Carnegie Mellon and the University of Michigan. As of August 2016, there were at least 30 companies developing AVs.[101]

States and universities are also partnering to create AV testing centers. For example, in 2014 the Michigan Department of Transportation partnered with the University of Michigan Mobility Transformation Center to build a $6.5 million facility to test how vehicles perform in complex urban environments.[102] Testing centers do not necessarily have to be completely self-contained: states like Ohio along with countries like Singapore and China have created "AV Zones" or "AV corridors" in industrial parks or managed freeways that serve to imitate the broad array of potential driving conditions without necessitating the construction of a new testing facility.[103]

G.1 States and cities should fund AV research programs at local universities.

Level 3, 4, and 5 self-driving cars and trucks are likely many years away from full-scale deployment. While the private sector has invested their resources into technology, universities can play an increasingly important role in understanding how AVs will integrate in to the transportation system. Testing centers, technology research, and other innovative investments can help understand and increase deployment so the general public can gain from the safety, environmental, and social benefits that AVs can provide.

H. Workforce Development

AVs have the potential to disrupt the economics of transportation and the industry at large in many ways. For example, if Level 3 vehicles proliferate first—before Level 4 or 5, fully self-driving cars—the most significant impact might be a reduction in car crashes due to the automated safety mechanisms. This may directly affect the 915,000 workers employed in auto repair and maintenance jobs in the United States.[104]

If Level 4 and 5 vehicles become widespread, there could be substantial job losses for taxi, truck, and other professional drivers. A study from Columbia University modeled such a scenario in the borough of Manhattan and found that a robotic fleet of 9,000 data-optimized, shared vehicles could operate a taxi service and have wait times of less than one minute, replacing the current fleet of 13,000 taxi cabs.[105] Applying this approach nationally would yield significant time, cost, and emissions savings, but would subsequently result in the potential loss of 233,000 taxi driver jobs across the United States.[106]

Furthermore, the perfection of AV technology and the automation of delivery services could threaten other jobs like bus drivers, delivery drivers, postal services, and truck drivers—occupations that represent almost 4 million jobs spread out across the country.[107] A 2016 report from the White House examined the implications of automation on the U.S. workforce and highlights AVs as a primary example of potential job loss for the nation. The report, which caveats that this loss could be over decades, highlights that truck drivers are the most likely be affected by automation.[108]

Of course, the rise of AVs might also lead to the creation of new industries and new occupations. It is too soon to tell exactly how AVs will disrupt the job market but it is certain that there will be a need for experts to maintain the vehicles, remote operators for fleets of AVs, and individuals to educate consumers, policymakers, and car distributors on the functions and limitations of AVs.

H.1 Federal, state, and local governments should work with academic institutions to retrain workers for jobs lost to automation.

With new levels of vehicle automation, the nature of truck, taxi and delivery drivers will change. The potential long-term loss of millions of jobs could threaten social and economic stability by accelerating income inequality.[109] Yet technology can improve existing working conditions, and education programs can prepare the workforce to better participate in the future economy. Governmental and university partnerships should work closely with the private sector to implement targeted retraining or career development programs that proactively address the negative impacts of automation.

IV. Conclusion

With the numerous issues around technology certification, liability, cybersecurity, data ownership, infrastructure funding, vehicle connectivity, environmental issues, and workforce development, AV policy is complex and complicated. The recommendations in this paper provide a clear and substantive framework for each level of government to use and support efficient, sustainable, and safe usage of this exciting technology.

Technology has always been an agent of change. Over the next decade, AV technology will rapidly alter the landscape of transportation. The implications will vary from insurance and certification, to infrastructure and the environment. As AV development continues to progress, appropriate and effective public policies are critical to managing safe deployment. Innovative and measured action now is necessary to lay the groundwork for the future.

End Notes and References

1 "Automated vehicles" is a broad term encompassing autonomous, self-driving, or driverless vehicles. It was first defined by the Society of Automotive Engine (SAE) and later adopted by NHTSA.

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